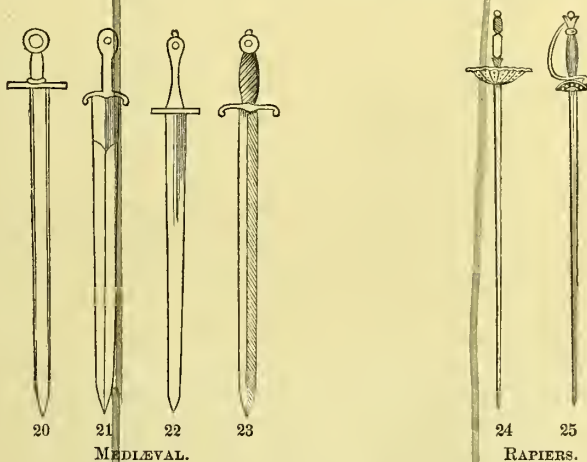


edged, and in time pointed. Finally, the Romans made the *gladius*—sharp, of highly-tempered steel, and strongly piercing—the first real sword (Figs. 17, 18, 19), of which only five specimens are now known to exist.

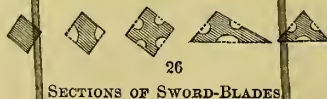
The well-tempered and well-made Saxon sword was the property only of those who had the rank of thane. As a rule, it was a straight, cut-and-thrust blade, with a double edge and a broad point, though other shapes have been found.

Of the three ways in which a sword may be used for cutting, that called chopping, in which the work is done with the shoulder and forearm and little play of the wrist, and the blow comes down straight with a whack, is of the most value against body-armor. The mediæval swords, therefore, were stout, straight, and wide (Figs. 20 to 23), and adapted to that kind of work. The hands being clad in mail, no attempt was made to protect them, and the hilts were plain and simple, except that a groove was sometimes made in the side of the blade to diminish the weight of metal without causing a loss of strength. The character of the sword varied little except as to the fashions suggested by fancy, till armor was done away with about 1600. Then, the change



of the sword into the single-edged weapon or the rapier-blade began to become common. While rapiers with flat or very slightly triangular blades, and often immoderately long, were used in France, Spain, and Italy in the sixteenth century, the full development of this form of arm (Figs. 24, 25) took place in the seventeenth and eighteenth centuries. The blades were narrow, the hilts had merely a single narrow guard for the back of the hand, with a broad base to protect the fingers in thrusting, and the rhomboidal or triangular section of the blade was altered, lightened, and stiffened by grooving (as in the group of figures, 26).

The fighting-swords of the latter part of the eighteenth and former part of the nineteenth centuries (Fig. 27) were not very good, either as rapiers or sabers, and marked a period of transition to one



almost of decadence. The cavalry-swords of the early part of the present century were clumsy and unscientific. With great width of blade and a tendency to increase the width toward the point (Fig. 28), they were not intended for cutting weapons, and were almost useless as thrusting ones. The idea that weight at the sword-end was valuable in enhancing the force of the cut was faulty in theory and practice, and was rather a retrogression to the principle of the axe than an advance in the true method of construction of the sword. This has given way to the modern sword, which combines within itself all the powers of which the weapon is capable, is good as a guard for thrusting and for cutting. Slightly curved, but not so much as to impede its pointing power, nor so wide as to be too heavy, stiffened by grooves so as to be capable of use as a rapier, its blade, with an edge on one side along its length, is flattened at the point, where it is ribbed, for strength, into a two-edged sword (Fig. 29). The



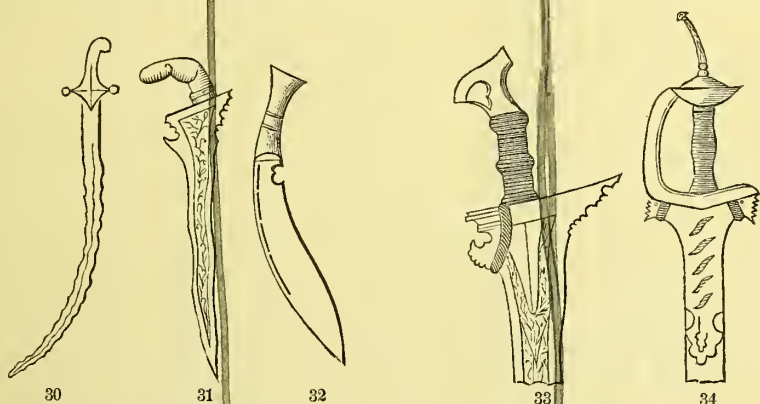
hilt has a wider guard, and is intermediate between the rapier type and that of the basket form. Adopting the principles that have obtained at various times, it is a good all-round weapon in skillful hands.

While Western nations have thus tended to adopt a straight blade, Eastern races have almost without exception preferred a curved sword. By reason both of their physical peculiarities and of the lighter character of the armor they wear, they have been accustomed to administer cutting blows with their weapons rather than the straight, down-right strokes that are adapted to Western strength and armor, and a curved edge is more suitable for cutting blows. The hilt of the Eastern sword is small, and the boss, or pommel, at the end of the hilt is large, so as to prevent the sword from slipping when the drawing cut is made. The Asiatic swords exhibit, moreover, greater divergencies of type than the Western swords. Some, like the Persian cimeters (Fig. 30), and the Malay creeses (Fig. 31), are often wavy, sometimes resembling the conventional tongue of fire (flamboyant), forms which may be due to the influence of the priests of the fire or the sun, or may be copied from the curvature and ornamentation of the antelope-horn dagger. The Albanian sword has the edge thrown forward by the

slight forward curvature of the blade, a feature which is heightened in the Goorkha knife, the owner of which, it is said, can decapitate an ox with one blow of it (Fig. 32). Some of the Eastern swords, as those of the Chinese, the Bashi-Bazouk or Circassian dagger, with its blade resembling the Roman gladius, and the Mahratta sword, are straight, like the Western weapons.

The ornamentation of all these weapons is very frequently only the survival of the methods by which the blades were fixed to their hilts, which was generally by thongs or rivets. Thus the Malay creese (Fig. 33) and the tulwar (Fig. 34) are made clearly to indicate the way in which the blade was originally lashed with cords to the hilt.

The sword does not rank so highly with savage nations as the spear



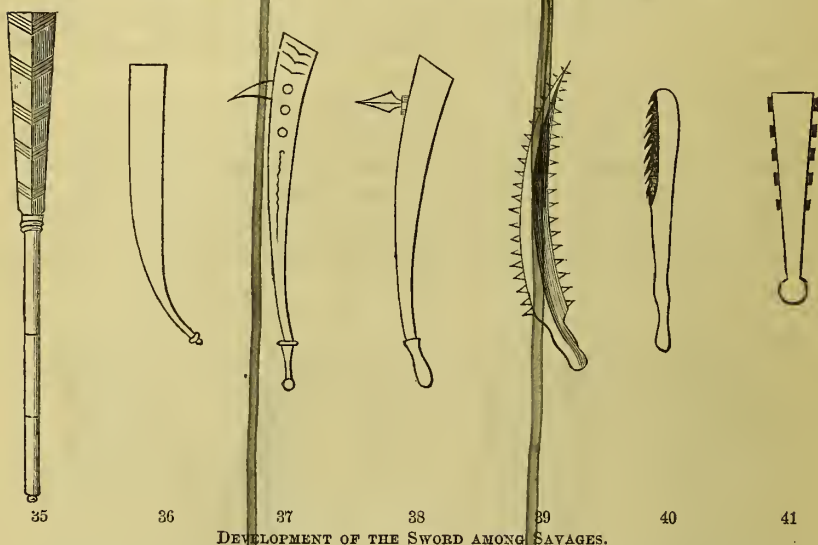
ASIATIC CURVED SWORDS.

SURVIVALS OF METHODS OF ATTACHMENT.

or club, and belongs to a higher civilization than that which is satisfied with hand-to-hand weapons of stone. But the development of the club into the sword is easily traceable, though the ultimate resultant is far inferior to the metal blades of even the bronze age. Figs. 35 to 41 show the successive steps. The New Zealand club (Fig. 35); the Indian collaree-stick (Fig. 36), often used as a missile; the Iroquois club (Figs. 37, 38), rendered good for piercing or cutting as well by a deer-horn point at first, and by an iron blade later on; the Marquesas (Fig. 39) or Tahiti cutting instrument, armed with sharks' teeth; the Esquimau or Australian sword (Fig. 40), in which strips of meteoric iron, obsidian, or glass are inserted in a cleft in the side of a stick, and fastened by cement; and, lastly, the Mexican maquahuitl (Fig. 41), or wooden sword, armed with sharp, razor-like flakes of obsidian, are the progressive steps of savage life toward the sword. The last-mentioned weapon was deadly enough to be ranked with its iron compeer, for it is said to have been capable of cutting off a limb. In this respect it is the highest type of a sword of other materials than metal.

Of all weapons, the sword has held throughout historic time the

highest place. Its use implied the personal courage of the individual at close quarters. The arrow might slay at a distance, and be discharged by a coward. The spear, again, if long enough and deftly



DEVELOPMENT OF THE SWORD AMONG SAVAGES.

held, could kill without risk to the holder thereof, unless the adversary were similarly armed. But the sword meant personal conflict, where the victory was not always to the strong. Rightly it is the sign of might and governance, for it implies both the will and the power to execute the behests of its holder. It is one of the insignia of authority, because it is the sign of courage and skill.

## ON THE DIFFUSION OF ODORS.

By R. C. RUTHERFORD.

THE following paragraph is similar to others I have occasionally seen going the rounds of the papers for the last twenty-five or thirty years :

It is said that a grain of musk is capable of perfuming for several years a chamber twelve feet square without sustaining any sensible diminution of its volume or its weight. But such a chamber contains 2,985,984 cubic inches, and each cubic inch contains 1,000 cubic tenths of inches, making in all nearly three billions of tenths of an inch. Now, it is probable, indeed almost certain, that each such cubic tenth of an inch of the air of the room contains one or more of the particles of the musk, and that this air has been changed many thousands of times. Imagination recoils before computation of the number of the particles thus diffused and expended. Yet have they all together no appreciable weight and magnitude.—*Moseley's Illustrations of Science.*

More than thirty-six years ago I announced, in some lectures I was then engaged in delivering, that there were some facts in the phenomena of odors and the sense of smell that were incompatible with the effluvia or diffusion-of-particles theory ; and I suggested an explanation based on the idea of a vibration or wave-motion, and an "odoriferous ether" analogous to, if not identical with, that of the luminiferous ether.

In the year 1863, in a letter to Professor Tyndall, I submitted the thought to him. After quoting some passages from his book, "Heat a Mode of Motion," upon the subject of odors, I wrote as follows : "I would respectfully ask if, in the consideration of, or in the course of, experiments upon this subject, it has ever occurred to you that *odor* might be as essentially a "mode of motion" as heat, light, or sound ? . . . The seemingly unlimited generation of odoriferous particles (?) by certain substances, without sensible diminution of bulk or weight, first led to the conception that, however copiously odoriferous particles of matter were disseminated through the atmosphere, the odorous property itself was as purely a specific variety of motion as the undulations of the luminiferous ether. That this *must* be the explanation of the action of the odor-generating force for a part of its route to the human sensorium seems to be incontrovertible, for it is hardly conceivable that the material particles should actually penetrate the membrane and force their way, as moving bodies, through the pulpy tissue of the nerves to the seat of sensation ; but that through that portion of their career, at least, their power is propagated by wave-like motions analogous to those of heat and sound."

Professor Tyndall did me the honor to answer my letter, but not to indorse my view, except in a very faint and qualified manner. Nevertheless, reflection and added experience have only gone to confirm me in the correctness of it, and I venture to predict that before many years it will be as much an accepted fact of science as the undulatory, luminiferous-ether theory now is.

In the case given above the entire space of the chamber is thoroughly impregnated with the perfume as much as if it were an absolute solid of odor. And yet these "particles," so profusely diffused through the room, are wafted away, and their places supplied by new emissions from the *undiminished* "grain," "many thousands of times" every year without appreciable "sensible diminution of its volume or weight," or pungency. This is an obvious impossibility upon any theory of molecular or atomic diffusion. The assumption of immense diffusibility and vastness of inter-particular spaces would only enhance the difficulty, for the odor spans the spaces—is as absolutely continuous as if the particles were in actual contact. That is, in the given space, the chamber, anywhere within the limits of the odor, there is no place where it is not. This *actio in distans* implies ethereal motion—vibration—between the particles.

May 1882

According to this view the odoriferous bodies, or their molecules, have no more to do (in the sense of physical impact) in producing the sensation of smell than a luminous body—a candle or the sun—has to do (by impact) with the sensation of light. There is corporeal impact or touch in neither case. Of course, with each molecule as a center of activity, the effect will be more pronounced at the immediate surface (as with all radiant energies) than at any distance. And, undoubtedly, particles of disintegrating, odorous matter are often brought in contact with the Schneiderian membrane; but the sensation of that impact, if there be any, would be of touch, not of smell, as surely as that, from that point of contact to the sensorium, the effect or influence is conveyed by a vibration—a wave-motion in the “fluid” of the nerve-duct—as the undulations of the luminiferous ether are propagated along the course of the optic nerve to the seat of sensation, where they are translated into light and color. But, if, for any portion of the distance between the internal sense and the fragrant body, the odor, like light, is but a motion, it is safe to assume it for all. The analogy of this mode of odors to that of light and sound is something in its favor.

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## COLOR-BLINDNESS AND COLOR-PERCEPTION.\*

By SWAN M. BURNETT, M.D.

TO physiologists that part of the function of vision which is concerned in the perception of colors has always been one of great interest, but it was not until the genius of Thomas Young offered them his theory of vision that they had anything like a plausible working hypothesis. This theory, as elaborated and promulgated by Professor Helmholtz, has until very recently been the one most relied upon in explanation of all the phenomena of colored vision. It is, however, a pure hypothesis, since not one of its fundamental principles is a demonstrated or even a demonstrable fact. By a process of deductive reasoning, and most probably with little, if any, experimentation—for it is said that Young prided himself on being independent of the necessity of experiment—the vivid imagination of this original mind seized upon an hypothesis which seemed to satisfy the demands of an acceptable theory, in so far as it accounted for all or nearly all of the observed phenomena. At that time, however, and even when Helmholtz resurrected and revived the theory, the question of color-blindness had not been investigated to the extent it has within the past ten years, and most physiologists rested content with the belief that at last the true theory of colors had been found.

\* A paper read before the Philosophical Society of Washington, December 18, 1880.

Such, however, is no longer the case, and there are many who are not almost but quite persuaded that the true theory of vision is one of the questions to be solved by the coming physiologist. This theory of Young-Helmholtz, as it is called, demands three primary or fundamental colors, by the admixture of which all other colors are produced. These colors are supposed, by Helmholtz, to be red, green, and violet. All other colors and shades are made from the proper mixture of two or more of these colors. White is the sensation produced by the proper mingling of all three sensations; black is the absence of sensation. Corresponding to these three primary sensations there are in the retina, or terminal expansion of the optic nerve, three distinct sets of nerves which respond to the wave-lengths of the luminiferous ether which physically represent these colors.

This is all very simple and extremely plausible, but certain phenomena of vision make it necessary to so modify this simplicity as to spoil its beauty and give an elasticity to the theory which can not be gratifying to the student of exact science. It becomes necessary to suppose, for instance, that the nerve-fiber which responds to red is also affected, in a less degree, by the green waves, and in a still less degree by the violet; and the green waves, while principally affecting the green fibers, affect also the red and violet; and the violet waves influence the red and green fibers, though in a much less degree than they do the violet. In this theory gray is but a white of diminished intensity.

Color-blindness is explained in keeping with this theory as follows: Any one or all three of the color-fibers may be wanting, or lacking in functional activity. Consequently there may be red-, green-, or violet-blindness, or there may be total color-blindness. Since, however, it is supposed that each one of the color-fibers is affected (though in a less degree) by both other colors as well as by its own peculiar color, there must be a sensation produced by each color, though it will be of lessened intensity in the case of the lacking color, and that sensation must be other than that of the color belonging to the missing fiber. Under these circumstances, even a saturated primary color would not, when its fiber was missing, appear black, though it would appear darker than to one with normal color-perception. To a red-blind person, a spectral red, for example, while appearing a color much less luminous than is usual, would not be black; and, if a solar spectrum were presented to such a color-blind individual, it need not appear shortened at the red end. If the green fiber is the lacking one, green will not appear as black, but when of a certain shade will appear as gray, and for the following reason: White is the product of the sum of all the sensations which the mind is capable of perceiving through the eye. When the eye is normal, we have it when all three of the fibers are affected in about the same degree, and in the color-blind when the two remaining fibers are thus affected. Any color, therefore, which contains, be-

sides green, a certain proportion of the other colors (red and violet)—as certain shades of what we call green do—will cause, when presented to such a green-blind individual, the sensation of white of diminished intensity. When the solar spectrum is placed before him, there should be a gray or neutral band at the line which divides the two colors which are unmistakably distinguishable; and, in the green-blind, it is nearer the red end of the spectrum than in the red-blind.

When the violet is the lacking fiber, we have phenomena analogous to those where the red fiber is missing, though, of course, there are differences in details.

In accordance with this theory, therefore, there can be no color-blindness, in the strict acceptation of the term, except when all the color-fibers are lacking; because all colors produce an impression of some kind, though it may not be the one experienced by those of normal color-perception. There is, however, a marked confusion of the various colors, and by the special character of this confusion one kind of color-blindness is differentiated from another.

In making an examination for the diagnosis of color-blindness, nomenclature, or the naming of the colors which are presented to the person to be examined, is entirely discarded. It has been found that an individual may be able to name the several colors correctly, and yet make mistakes when called upon to match them; and, on the other hand, he may not be able to name a single color correctly, and yet make no serious mistakes in "matching." The method of comparison is therefore the only one which should be adopted in making examinations for color-blindness.

The method of Professor Holmgren, which is the simplest and, on the whole, the most convenient, consists in placing on a table before the examinee a large assortment of skeins of colored worsteds. A "sample" skein of light-green is laid to one side, and the individual is told to select from the pile all the skeins which are of the same color—lighter or darker. If he places by the sample a shade of any other color but green, he is color-blind. This examination, however, does not fix the particular color to which he is blind, and, in order to find the color which is lacking in his chromatic scale, a purple or rose-colored skein is laid aside as a sample and the confusions he makes here are supposed to fix the diagnosis. If he matches the purple with blue and violet or one of them, he is *red-blind*. If, however, he selects the greens and grays, he is *green-blind*. *Violet-blindness* (which is very rare) is recognized by a confusion of red, purple, and orange in the test with the purple skein.

Another plan for employing the comparative method is to have two solar spectra, one above the other, the upper of which is movable. A colored band is isolated in the fixed spectrum, and the upper spectrum is moved until what is supposed to be the same color is immediately above it. Or, the isolated band may be matched with a skein of

colored wool. Of course, the same mistakes will be made here as in the preceding method.

Another method of examination rests on the phenomena of what are called contrast colors. When a white surface is illuminated simultaneously by a red and a white light—as by two lamps, for example, before one of which a red glass is held—an object, a pencil, for instance, held midway between the two will cast two shadows, one from the red light and another from the white light. To one of normal color-perception, one of these shadows (that cast by the white light) will be red, while the other (that cast by the red light) will be green; to any one blind for either one of these colors, there will be no difference in the color of the shadows. If rings cut from black or gray paper are laid upon red or green paper and the whole is covered with tissue-paper, the rings will have a reddish tinge if the ground is green, and green if the ground is red. If, however, the individual is blind to either of these colors, no such difference will be noted; and, if letters cut from black or gray paper are used instead of rings, they can not be distinguished when laid on the colored ground and covered with the tissue-paper.

Another method is to make letters of certain colors on different colored grounds—shades of red letters, for instance, on a green ground. When these are of the requisite tints, the color-blind person is not able to distinguish them.

There are other methods, but they are all modifications to a greater or less extent of the foregoing, and any one who is color-blind to any considerable degree can be detected by any one, or at least by any two, of the methods indicated.

There is another theory of colors brought forward within the last few years by Professor Hering, of Prague, which is adhered to by many physiologists, and is a vigorous rival of the Young-Helmholtz theory. Professor Hering assumes that there are three chemical visual substances in the retina, which he calls the *black-white*, the *red-green*, and the *blue-yellow*. Light acts upon these substances by what he calls assimilation (A), and dissimilation (D). When light acts in a dissimilating or decomposing manner on the black-white substance, the sensation of white is produced; when there is an assimilation or regeneration of this substance, the sensation is black. Hering is by no means certain which are the A- and which the D-colors, but he is disposed to regard red as the dissimilating color of the red-green substance, and green the assimilating color. Blue, he thinks, causes dissimilation of the blue-yellow substance, while its regeneration is caused by yellow. All colors, he supposes, act in a dissimilating manner on the black-white substance—that is, they produce the sensation of white in addition to their own peculiar color. They act, however, in varying degrees of intensity, yellow acting with the greatest power, the strength of action diminishing toward the two ends of the spectrum.

In accordance with this theory, there are, therefore, four fundamental colors instead of three (excluding black and white), namely: red, green, yellow and blue, and they are supposed to be produced as follows: Red is the product of the dissimilation of the red-green substance, green is the result of its assimilation; blue is the result of the dissimilation of the blue-yellow, and yellow of its assimilation. When the A- and D-action on the red-green and blue-yellow substance are equal there is no color sensation, but only the D-action of these colors on the black-white substance, that is white. Simultaneous A- and D-action on the black-white substance, however, is not attended by abolition of sensation, but by the sensation of gray.

It will be seen from this that, in the Hering theory, what were before considered as *complementary* colors are *antagonistic* and tend to neutralize each other. It will be remembered that those colors have been called complementary which, when mixed together, would produce white (we speak now of spectral colors). This was explained by the Young-Helmholtz theory on the principle of combination; it is accounted for by the Hering theory on the principle of subtraction. When red and green, for instance, form white on being mixed, the white is not produced by the sum of the sensations of red and green, but the red and green, being antagonistic, neutralize each other, and there only remains the D-action of both colors on the black-white substance—that is, white.

As in the Young-Helmholtz theory, the other colors, aside from the primary, are the results of mixed sensations.

Color-blindness, in accordance with this theory, is of two forms. In one, both color substances are wanting, and there only remains the black-white substance to be acted on by light (achromatopsia). In the other form, one of the two color-substances is lacking and only the two colors of the remaining color-substance are distinguishable (dichromatopsia). If the red-green substance is lacking, there will be red-green blindness or blue-yellow vision; if the blue-yellow substance is the missing one, there will be blue-yellow blindness, or red-green vision.

To satisfactorily account for some of the phenomena of color-blindness, however, it becomes necessary to suppose that, when one color-substance is wanting, the light rays which act specifically on that substance produce an A- or D-action on the remaining color-substance. In red-green blindness, for example, red, yellow, and green act in a dissimilating manner on the remaining blue-yellow substance, giving rise to the sensation of yellow, while blue alone acts in an assimilating manner. The most strongly dissimilating color will be yellow, while the others will be more or less varying in their action. In the case of blue-yellow blindness, red, yellow, and blue are the dissimilating colors and green the assimilating color. It will be readily understood, when we have this state of affairs, that in the dichromatope, where

the A- and D-action of the one remaining color-substance are equal, gray will be the result, because, as we have before remarked, where two colors neutralize each other there still remains the action of both on the black-white substance, which will give rise to the sensation of gray or white of diminished intensity. But the same colors will not appear gray to all color-blind persons, for the reason that the same colors do not act in every case with the same intensity of dissimilation and assimilation. In most individuals it is the purple and the blue-green which give rise to the impression of gray.

A spectrum should, in accordance with this theory, appear in only two colors to the color-blind, and may or may not be shortened according as the dissimilating power of the two remaining colors is intense or very feeble. The only colors, of course, which such a color-blind person can with certainty distinguish are the two belonging to the one remaining color-substance, blue and yellow, for instance, when there is red-green blindness, and red and green when there is blue-yellow blindness. It is not to be understood, however, that such an individual can never correctly distinguish other colors. Most frequently he can, but there is always a liability to confusion, often of the most astonishing character; and, moreover, the distinctions are made, not by the sense of color, but by some other characteristic, different degrees of luminosity, most commonly.

The evidences which the phenomena of color-blindness have brought against the three-fiber theory of Young-Helmholtz are:

1. That the red-blind can not distinguish perfectly the greens and violets, nor the green-blind the reds and violets; yellow and blue being the only colors about which they make no mistakes.

2. Even in a spectrum which is very much shortened the red-blind finds the brightest place, not in the bluish-green, as we should expect, but in the yellow, as in the normal eye.

3. This theory can not satisfactorily explain the extreme shortening of the spectrum, extending, as it sometimes does, into the orange, and even into the yellow.

4. The line of demarkation in the spectrum is sharply at the blue, all to the left almost always appearing of one color, and all to the right of another, there being no lines of division between blue and violet, nor between the red and yellow and the yellow and green.

5. The gray or neutral band is far from being invariably present, and when it is it is often, in the red-blind, in the position it should be in the green-blind, and *vice versa* (Mauthner).

Against the Hering theory the following objections have been advanced:

1. There is no reason for supposing that red and green and blue and yellow are opposing colors. They are all active in their specific line, and even Hering has not been able to determine which possesses the A-action and which the D-action.

2. The simple colors are not complementary, as Hering asserts; blue-green, and not green, is the complementary color of red, and violet-blue, and not blue, is the complementary color of yellow. The simple colors can not, therefore, be considered as antagonistic.

3. The white, which comes from the union of two of Hering's antagonistic colors, is not the result of subtraction, but of addition, as is shown when, with a double spectroscope, a saturated violet being made to cover a yellow, a white is produced which is manifestly more intense than the yellow, while another yellow of the same intensity as the violet added to the yellow does not produce a yellow intenser than the yellow resulting from the first experiment.

4. White is not a direct independent sensation; it is absent in the spectrum where, in red-blindness or violet-blindness, the specific color is absent (Donders).

From the foregoing, and from a study of the phenomena as presented by a number of color-blind persons, two important facts are forced upon the unbiased observer: 1. That we have not yet arrived at any fixed laws governing the phenomena; that all cases can not be classed as distinctly red, green, or violet blindness, though it seems probable that all might be classed under the heads of red-green and blue-yellow blindness. 2. That neither of the two prominent hypotheses fills the demands of an acceptable theory, inasmuch as both fail to account consistently for all the phenomena.

It seems to us that, in the consideration of the subject of color-blindness hitherto, too much stress has been laid on the part which the retina plays in color-perception. There are three distinct agents at work in the perception of color. The impression is first made on the retina; this is carried thence by means of the optic nerve to the center in the brain which presides over the function of vision, and it is there converted into a sensation. Let any one of these agents become incapacitated, from any cause, for properly carrying on its function, and there must be a perversion or absence of sensation. In certain affections of the retina and optic nerve we have instances of color-blindness from deranged or abolished functional activity of the first two agents, and in some forms of toxic action, particularly alcoholic poisoning, we have in all probability examples of the cerebral form of color-blindness. The supposed color-fibers or color-substances may be in a perfect condition and acted upon in a perfectly normal manner by light, but the optic nerve may be incapacitated by some change in its molecular structure from carrying all of the impressions correctly to the brain-center, and, even should all the separate impressions arrive there, the cerebral center itself may not be in condition to convert them into the proper sensation. The conducting power of the nerve, or the converting power of the cerebral center, may be but slightly deranged or totally deficient for some color or colors, and so the phenomena presented by two cases falling under the same category would be very different;

and, when we consider the infinite degrees of incapacity that may exist for all the different colors, we can readily understand the infinite variation in the mistakes of the color-blind, and the impossibility of laying down exact rules for diagnosis.

It is my belief that a large number, perhaps a majority, of the cases of congenital color-blindness have not their seat in the retina at all, but are cerebral in their character. In other words, I believe that in these cases the brain-center of vision has not the power to differentiate the various impressions it receives. This opinion will seem the more plausible when we remember that the sense of sight is a developed or educated one. Though we have received from our ancestors the potentiality of vision, every child that is born must learn to see for itself. Without here entering into a discussion of the question of the development of the color-sense, which has received much attention at the hands of Mr. Gladstone, Magnus, and others, it is safe to assume, with our knowledge of analogous matters, that the differentiation of colors is a power partly inherited and partly developed in the individual; and, moreover, we should expect to find this power, which is undoubtedly cerebral in its character, most strongly developed where the faculty was most used. And so we do find it. Women, who are much more concerned than men in the selection and comparison of colors, are rarely affected with color-blindness; and we all know how much quicker the feminine eye is in detecting slight differences in shades of color than is that of men who are not color-blind. In those cases of color-blindness which, for the sake of distinction, we shall call central, we believe that the brain-center of vision has not been developed to its full or at least to its ordinary power for discriminating between the impressions corresponding to the different colors. The retina may be capable of properly responding to these various impressions, and the optic nerve may carry them as separate impressions to the brain-center; but this has not the power of converting them into individual sensations.

From what has already been said, it is evident that neither of the two at present prominent theories satisfactorily accounts for all the phenomena of color-blindness. Moreover, it seems to me, the true theory of colors when found will be simple; and the laws governing the sense of vision will be found to bear some analogy to those governing the other senses—at least, I do not believe it will be found necessary to invent new processes and new reactions of tissues to agents affecting the economy. The true theory, I believe, will be found to lie in the direction pointed out by the recent researches on the physical reaction of certain simple substances to the undulations of the luminiferous ether. This reaction may be in its restricted sense chemical, purely physical, or chemico-physical; but it will be due to the changes in the molecular structure of simple substances, caused by the action of the ether. In other words, *the variation in the sensation*

*produced will have its basis, not in complexity of tissue, but in the varying action of the affecting agent.*

Without entering into a discussion of the question in detail, I would say that it seems probable that the optic nerve is merely a highly organized nerve of common sensation. In some of the lower forms of animal life light is perceived over the whole cutaneous or external surface, as shown by the action of the animals when exposed to its influence. Furthermore, it is now a generally admitted fact that heat and light are due to vibrations of the same ether, differing only in their wave-lengths. The effect of both heat and light is to produce molecular change. When heat produces a sensation through the cutaneous nerves, it is most probable that it does it by means of a molecular change in the terminal filaments of these nerves which is communicated to the brain-center through the nerves, probably also by a rapidly progressive change in their molecular structure. The nerves of common sensation, however, do not seem to possess the power to differentiate variations in wave-lengths—they take cognizance only of the varying intensity of the vibratory motion; that is to say, they distinguish quantities rather than qualities. It would, however, be doing no violence to known facts to suppose that a high specialization would enable these nerves to carry as distinct impressions the changes wrought by the separate wave-lengths. In fact, it is highly probable that they do so, but the cerebral centers in which they terminate have not been educated to the point of making distinctions between these separate impressions and fixing them as individual sensations.

In framing a theory of color-perception on the basis we have indicated, we would suppose the retina to be a body whose molecular structure is such that it will respond with promptness to all or nearly all the wave-lengths of perceptible light. This molecular change produced in the retina is carried by the optic nerve to the center of vision in the brain, and is there converted into a sensation. This is, to some extent, going back to the original theory of Newton, who, in speaking of the action of light upon the retina, considered that "the rays impinging upon the ends of the optic nerve excite vibrations which run through the optic nerve to the sensorium. Here they are supposed to affect the sense with various colors according to their nature and bigness."

The chief objection to this hypothesis, advanced by Young, was that the frequency of these vibrations must be dependent upon the constitution of the substance of the retina, and it was almost impossible that every sensitive point should have an infinite number of different particles to respond to this infinite number of vibrations. He therefore supposed the number to be limited to three which corresponded to red, green, and violet.

It will be seen that the difference in the different theories of colors lies in the supposed reaction of the retina to light. After the impres-

sion has passed beyond the retina, there is no special or important difference in the views as to the final conversion into a sensation. The objections to these two hypotheses we have already stated. The acceptance of such an hypothesis as we propose, however, does not involve the necessity of inventing new laws, or of creating new issues, but only applies known laws and analogous reactions of other substances to the elucidation of the phenomena observed. We know that there are membranes which respond with promptness to any number of simple aerial vibrations at the same time, and recent discoveries have shown that there are substances which, when in proper condition, thus respond to wave-lengths of light. Silenium, when in a crystalline condition, alters its molecular condition (as manifested by its varying resistance to the passage of the electric current), not only when acted on by light of varying intensity, but also by the different wave-lengths. If, then, we suppose the retina to be a substance of this nature, but responding more promptly, and in a more delicate manner, than any other known substance to the wave-lengths of light, we have a basis for a theory of vision which is extremely simple in its nature, and founded on known physical laws.

We will not here enter upon a detailed application of this theory to the elucidation of all the phenomena of colored vision, but will simply mention a few points in connection with color-blindness. One general principle may be laid down which will cover all cases of retinal color-blindness as distinguished from cerebral or central, and that is, that in these cases the molecular structure of the retina is so altered as to allow it to respond feebly or not at all to light rays of certain wave-lengths. We know, for example, that silenium must be in a crystalline state—that is, its molecular structure must be in a certain definite condition—before it can respond in such a delicate manner to variation in the intensity of the light-waves; and we know that there are certain wave-lengths of the ether—the ultra-red and the ultra-violet—which call forth no reaction on the part of the retinal substance. It would, therefore, be a highly justifiable supposition that a slight alteration in the molecular structure of the retina would render it incapable of being affected by certain wave-lengths to which it, when in a normal condition, readily responds. This incapability may be partial or complete as regards any particular wave-lengths. In some instances of color-blindness, for example, the spectrum is shortened at the red end even under the most intense illumination, while in others there is a shortening only when the illumination is feeble—becoming of normal length when the intensity of the illumination is increased—showing, in the latter case, that the reaction to the red rays is still present when they are of sufficient intensity.

When we come to cerebral color-blindness, which is, according to my view, the most common, the explanation is still simple. In this instance we have only to suppose the cerebral center of vision incapa-

ble of distinguishing between the impressions of wave-lengths which lie relatively near together as regards their vibration numbers. It will be noticed, as an important fact, that there is confusion only of those colors which lie toward the same end of the spectrum. Red and green, for instance, are the colors which are most commonly undistinguishable; blue and yellow less commonly; but no instance is on record in which red and blue, or green and yellow, were constantly confounded. It seems from the examinations thus far made that the color-blind make, as a rule, distinctions between only two classes of color-sensations. A most intelligent color-blind man, whom I recently examined with the spectrum, saw it only as two colors—the line of demarkation being sharply at the blue-green junction, all to the right was blue, all to the left was what he called red. He could distinguish no line of separation between the red, green, and yellow, and the maximum of intensity was at the yellow, as is the case with normal eyes. As Mauthner says, there are no fixed rules which serve us for a diagnosis between red- and green-blindness. The two colors are confused, but how are we to know which is the one correctly perceived? The individual who is found to be green-blind by one method of examination is often found to be red-blind by another, and in some cases to have a shortening of the red end of the spectrum. Moreover, the red-blind can not unerringly pick out the greens, nor the green-blind the reds.

If, as we believe, a large number, perhaps a majority of the cases of congenital color-blindness are cerebral rather than retinal, and due more to a want of education of the color-sense than to any anatomical defect, a plan for the diminution or eradication of color-blindness would be by no means chimerical. The fact that women are less frequently color-blind than men we consider most probably due to the circumstance that their faculty for color is in more active and constant use, and for this reason has become more highly developed, and has been transmitted as a sexual peculiarity from mother to daughter. It seems, therefore, quite reasonable to suppose that if boys could have their color-sense educated to the same extent as girls, and the process were continued through a number of generations, the defect of color-blindness would in course of time disappear, except as a rare anomaly.



## STALLO'S "CONCEPTS OF MODERN PHYSICS." \*

By W. D. LE SUEUR.

"IT is generally agreed," says Mr. Stallo, "that thought in its most comprehensive sense is the establishment or recognition of relations between phenomena." All perception is of difference; and two

\* From a criticism of "The Concepts and Theories of Modern Physics," in the "Canadian Monthly."